INTERNATIONAL MARITIME ORGANIZATION

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MARINE ENVIRONMENT PROTECTION COMMITTEE
70th session
Agenda item 4

MEPC 70/INF.22
17 August 2016
ENGLISH ONLY

HARMFUL AQUATIC ORGANISMS IN BALLAST WATER

Information on the type approval of the Semb-Eco LUV 500 ballast water management system

Submitted by Singapore

SUMMARY

Executive summary:	This document informs that the Singapore Administration has type approved the Semb-Eco LUV 500 ballast water management system in accordance with the *Guidelines for approval of ballast water management systems* (G8), in compliance with regulation D-3.1 of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004
Strategic direction:	7.1 and 13
High-level action:	7.1.2 and 13.0.3
Output:	7.1.2.4 and 13.0.3.1
Action to be taken:	Paragraph 7
Related documents:	Resolutions MEPC.174(58) and MEPC.228(65)

Introduction

1 Regulation D-3.1 of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004, provides that ballast water management systems must be approved by the Administration taking into account the guidelines developed by the Organization.

2 The Singapore Administration hereby notifies the Organization of its decision to type approve the Semb-Eco LUV 500 ballast water management system in accordance with the *Guidelines for approval of ballast water management systems* (G8).

3 The Semb-Eco LUV 500 system is a non-chemical ballast water management system whereby ballast water treatment is achieved through a two-stage process. It uses liquid–solid separation and low pressure amalgam UV to treat ballast water and also incorporates a bio fouling control (BFC) unit.

4 Land-based tests were conducted by DHI Singapore from 3 December 2013 to 28 March 2014, and shipboard tests in the period from 20 January 2015 to 4 August 2015. A summary of the test results can be found in annex 2 to this document.

Information reporting on type approved ballast water management systems

5 In accordance with resolution MEPC.228(65) *Information reporting on type-approved ballast water management systems*, the following information is provided:

.1 approval date: 27 July 2016;

.2 name of the Administration: Singapore;

.3 name of the BWMS: Semb-Eco LUV 500;

.4 a copy of the Type Approval Certificate can be found in annex 1;

.5 results from land-based and shipboard testing have been included in annex 2 of this document; and

.6 the protocol according to which testing was undertaken, including details on:

.1 whether ambient, cultured or a mixture of test organisms have been used (including a species-level identification for cultured organisms, and an identification to the lowest possible taxonomic level for ambient organisms);

.2 the shipboard test protocol including the operating parameters of the system during successful treatment operations, for example dosage rates, UV intensity and electrical current applied;

.3 energy consumption of the ballast water management system under normal or tested Treatment Rated Capacity (TRC);

.4 the full test report of the land-based test including all unsuccessful, failed and invalid tests;

.5 the full test report of the shipboard test including all unsuccessful, failed and invalid tests, and detailed information of the test set up and actual flow rate at each test cycle; and

.6 QA/QC documentation of the testing facility or body.

6 The documents mentioned in paragraph 5.6 and all further information can be obtained by making an e-mail request to: SIASsingapore@lr.org

Action requested of the Committee

7 The Committee is invited to note the information contained in this document.

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ANNEX 1

TYPE APPROVAL CERTIFICATE FOR THE SEMB-ECO LUV 500 BALLAST WATER MANAGEMENT SYSTEM

Lloyd's Register

Type Approval Certificate of Ballast Water Management System

This is to certify that the Ballast Water Management System listed below has been examined and tested in accordance with the requirements of the specifications contained in the Guidelines contained in IMO resolution MEPC.174(58). This certificate is valid only for Ballast Water Management system referred to below.

Ballast Water Management System supplied by:	Sembcorp Marine Repairs & Upgrades Pte. Ltd.	
Under type and model designation and incorporating:	Ultra Violet irradiation incorporating filtration and biofouling control	
Ballast Water Management System manufactured by:	Sembcorp Marine Repairs & Upgrades Pte. Ltd.	
Address of Manufacturer:	Admiralty Road West, Singapore. 759956	
Name of BWMS:	Semb-Eco LUV 500	
To equipment/assembly drawing No:	BWXN0500-201-O-001, rev C4	**Date: 02 June 2016**
Other equipment manufactured by:	N/A	
To equipment/assembly drawing No:	BWIN0500 TAA 901 T 001, rev C5	**Date: 24 June 2016**
Treatment Rated Capacity:	500	**M³/h**

A copy of this Type Approval Certificate should be carried on board a vessel fitted with this Ballast Water Management System at all times. A reference to the test protocol and a copy of the test results should be available for inspection on board the vessel.

Limiting Conditions imposed are described in the attached Design Appraisal Document (schedule), which forms part of this Type Approval Certificate.
This Type Approval Certificate shall remain valid until its Expiry Date, unless otherwise (a) cancelled or revoked by the Director of Marine, Maritime Port Authority of Singapore (MPA), or (b) the requirements or specifications of the IMO or the MPA, applicable to this type approval certification process are revised or superseded, whichever earlier, provided the conditions in the attached schedule are complied with and the equipment remains satisfactory in service.

Date of issue	27 July 2016	Expiry date	26 July 2021
Certificate No.	MCA 1600014	Signed	
Sheet No	1 of 7	Name	S. Abeysekara

Sahan Abeysekara
Southampton GTC Office Office
Lloyd's Register EMEA

Surveyor to Lloyd's Register EMEA
is a subsidiary of the Lloyd's Register Group

Note:
This Type Approval Certificate is issued on behalf of the Director of Marine, Maritime and Port Authority of Singapore.

This Type Approval Certificate is not valid for equipment, the design or manufacture of which has been varied or modified from the specimen system tested and certified hereby. The manufacturer should, in the event of such variation or modification, notify, re-apply and obtain a fresh certificate from the Maritime and Port Authority of Singapore through Lloyd's Register of any modification or changes to the equipment, design or manufacture of the ballast water management system.

Lloyd's Register EMEA
Marine Technology & Engineering Services
71 Fenchurch Street, London, EC3M 4BS
Telephone 020 7709 9166 Fax 020 7488 4796
Email tass@lr.org

Page	2 of 7
Document number	MCA 1600014
Issue number	1

DESIGN APPRAISAL DOCUMENT

Date	Quote this reference on all future communications
27 July 2016	MTES/ENG/TA/SA/WP17862506

ATTACHMENT TO CERTIFICATE OF TYPE APPROVAL No. MCA 1600014

This Design Appraisal Document forms part of the Certificate MCA 1600014

APPROVED RATINGS IN CERTIFICATE NO. MCA 1600014

BWMS	UV REACTOR	FILTER	BFC UNIT
LUV 500	LBW 240	Omega II	BFC A

LUV 500 BWMS

Pressure rating Max 6 bar
Water temp 0 to 60^{0}C
Ambient temp 5 to 55^{0}C
Min flow 60 m3/h
Max TRC 500 m3/h

UV Reactor Model

LBW 240

Material: Stainless steel 316
No. of lamps: 24
Amalgam Low pressure with Quartz sleeve
UVT: min 50%
UVI: min 80 W/m^2

Self-cleaning Filter

Omega II

Filtration degree: 25 µm
Filter screen: stainless steel
Filter house: Carbon Steel

Bio Fouling control unit

BFC A

BFC housing: Carbon Steel
Operating range: time varying frequency 50 – 200 kHz

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Page	3 of 7
Document number	MCA 1600014
Issue number	1

DESIGN APPRAISAL DOCUMENT

Date	Quote this reference on all future communications
27 July 2016	MTES/ENG/TA/SA/WP17862506

ATTACHMENT TO CERTIFICATE OF TYPE APPROVAL No. MCA 1600014

Land based test summary (ND = Not Detectable)

Size category	Sample	Test Cycle									
		Brackish (~22PSU)					Marine (~33PSU)				
		SBOBW1	SBOBW2	SBOBW3	SBOBW4	SBOBW5	SBOMW 1	SBOMW 2	SBOMW 3	SBOMW 4	SBOMW 5
≥ 50 µm (#/m^3)	Intake Test	127065	116957	106667	280000	360000	370000	426667	423333	307778	390000
	Control discharge	44000	59333	56000	23500	157667	52133	62333	20267	62000	58667
	Treated discharge	5	7	3	1	3	0	0.3	0	0.3	6
≥10 and <50 µm MPN (#/mL)	Intake Test	2333	>9200	>9200	2900	1743	2167	>4300	1613	3167	4167
	Control discharge	>1661	847	>371	248	254	609	686	1025	343	564
	Treated discharge	<3.18	4.44	0.91	<4.18	<1.88	<0.18	<0.18	<3.18	>0.36	<0.18
Hetero-trophic Bacteria (CFU/ml)	In. control	266667	232000	415667	277333	1596667	255333	284000	451333	125333	283667
	In. test	294000	292000	290000	238000	1433333	257333	532667	501667	448333	673333
	Dis control	453667	330667	2848667	491667	309667	691333	304333	590000	117000	68667
	Dis treated	183	117	63	371	41	5	<1	<1	<1	5.7
E. coli (CFU/100 mL)	Control discharge	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Treated discharge	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Entero-cocci (CFU/100 mL)	Control discharge	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Treated discharge	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Vibrio cholera CFU / 100ml	Control discharge	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Treated discharge	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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DESIGN APPRAISAL DOCUMENT

Date	Quote this reference on all future communications
27 July 2016	MTES/ENG/TA/SA/WP17862506

ATTACHMENT TO CERTIFICATE OF TYPE APPROVAL No. MCA 1600014

Shipboard test summary

Size category	Sample	Test Cycle		
		1	2	3
Organisms ≥ 50 µm (per m^3)	Control Uptake	4392	2863	7314
	Control Discharge	1389	252	3448
	Treated Uptake	3440	2413	4534
	Treated Discharge	ND	ND	ND
Organisms < 50 ≥10µm (per ml)	Control Uptake	286	623	104
	Control Discharge	84	70	38
	Treated Uptake	319	1002	100
	Treated Discharge	0.7	1.0	0.3
***Escherichia coli* (CFU/100 mL)**	Control Uptake	4	6	90
	Control Discharge	ND	<5	<5
	Treated Uptake	8	8	70
	Treated Discharge	ND	ND	1.7
***Intestinal Enterococcus* (CFU/100 mL**	Control Uptake	100	<5	<10
	Control Discharge	24	<5	ND
	Treated Uptake	18	<5	<5
	Treated Discharge	2.3	ND	ND
***Vibrio cholerae* (CFU/100 mL)**	Control Uptake	ND	ND	ND
	Control Discharge	ND	ND	ND
	Treated Uptake	ND	ND	ND
	Treated Discharge	ND	ND	ND

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Page
5 of 7
Document number
MCA 1600014
Issue number
1

DESIGN APPRAISAL DOCUMENT

Date	Quote this reference on all future communications
27 July 2016	MTES/ENG/TA/SA/WP17862506

ATTACHMENT TO CERTIFICATE OF TYPE APPROVAL No. MCA 1600014

APPROVAL DOCUMENTATION

Request form	10 April 2014
Test plan for Semb-Eco Environmental testing, TVU SUD PSB pte Ltd	12 Nov 2015
Environmental test protocol, BWXN0000 010 G 001, Rev C10	12 Nov 2015
Technical Manual, BWIN0500 TAA 901 T 001, Rev C5	24 June 2016
Systems warnings and Alarms, BWXN0000 001 G 001, Rev C11	10 Sep 2015
P&ID BWTS, BWXN0500 201 O 001, Rev C4	02 June 2016
Software quality plan BWIN0500 002 G 001, Rev I1	06 May 2015
Software change handling & revision control BWXN0000 011 G 001, Rev I1	07 July 2015
Bio Fouling Control system, BWXN0000 013 G 001, Rev C3	27 April 2016
Control system overview diagram, BWXN0500 301 V 002, Rev C2	24 June 2016
Power system single line diagram, BWXN0500 301 V 001, Rev C2	24 June 2016
Quality assurance project plan, land based test	Dec 2013
Quality management plan, land based test	Dec 2013
Quality assurance project plan, ship board test	May 2014
Quality management plan, ship board test	May 2014
Sampling protocol, ship board test	May 2014
Machinery General Design Appraisal for Wedeco UV- Reactor and Control Cabinet manufactured by Xylem Water Solutions GMBH used on Ballast Water Management Systems, HTS/ETS 33522-16	26 April 2016

TEST REPORTS

BFC unit & BFC cabinet voltage variation test, No 7191118025-EEC16/10	05 Feb 2016
Test report Cabinet control 48BW HX with UV reactor LBW 240, No E154248E1	01 Feb2016
Remote I/O and PLC cabinet voltage variation test, No 7191118025-EEC16/04	22 Jan 2016
Product reliability test on PLC panel & Remote I/O panel, No 7191118025-EEC15/01-AFI	11 Dec 2015
Remote I/O and PLC cabinet Environmental test, No 7191118025-EEC15/02-PCA	27 Jan 2016
BFC cabinet Environmental test, No 7191118025-EEC15/07-PCA	15 Feb 2016
Product reliability test on BFC & BFC cabinet, No 7191118025-EEC16/06-AFI	28 Jan 2016
Test report Control cabinet U160347E2, 2ND version	30 March 2016
Test report Control cabinet & Reactor U154248E1,	23 March2016
Land based testing of the Semb-Eco BWMS, Final report, Rev 2	May 2014
Final report ship board test Semb-Eco BWMS	Sep 2015

SUPPORTING DOCUMENTS

Risk Assessment report, BWIN500 004 G 01,Rev C1	02 Dec 2013
Vendor data, Semb-Eco L-UV chamber, BWIN500 002 T 01, Rev C1	04 Dec 2013
Vendor data, Auto back flush screen filter, BWIN500 001 T 01, Rev C1	02 Dec 2013
Comment Xylem to vibration test report U160347E2 issued by phoenix test lab	30 March 2016

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Page
6 of 7
Document number
MCA 1600014
Issue number
1

DESIGN APPRAISAL DOCUMENT

Date	Quote this reference on all future communications
27 July 2016	MTES/ENG/TA/SA/WP17862506

ATTACHMENT TO CERTIFICATE OF TYPE APPROVAL No. MCA 1600014

CONDITION OF APPROVAL

The BWMS is to be operated by trained personnel only. Manufacturer's instructions and common industry safety practises are expected to be followed. Manufacturer is to provide training to the satisfaction of the client.

The BWMS is to be installed and commissioned in accordance with Section 8, Installation Survey and Commissions Procedures of MEPC 174(58) and relevant classification society rules and regulations.

The BWMS installed in areas where an explosive gas atmosphere may be present, are to be of a type providing protection against ignition of the gases encountered and to be certified accordingly.

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Page
7 of 7
Document number
MCA 1600014
Issue number
1

DESIGN APPRAISAL DOCUMENT

Date	Quote this reference on all future communications
27 July 2016	MTES/ENG/TA/SA/WP17862506

ATTACHMENT TO CERTIFICATE OF TYPE APPROVAL No. MCA 1600014

CONDITIONS OF CERTIFICATION

1. Within five years, the manufacturer must submit a report to the Singapore competent authority, the Director of Marine of the Maritime and Port Authority of Singapore (MPA), detailing all experiences with the operation of the ballast water management system, including results and analysis of any scientific research relevant to the safe operation and environmental impact of the system.

2. In addition, the manufacturer shall also comply with the following additional provisions:

   2.1 The manufacturer must report immediately all events to the MPA leading to harm either to human health or the environment as a result of the operation of the ballast water management system.

   2.2 Any indications that the ballast water management system is not performing to the standards of the ballast water convention must be reported to the MPA including any deficiencies identified by port State control.

   2.3 All accidents (e.g., accidental exposure to UV) in connection with the ballast water management system must be reported immediately to the MPA.

   2.4 Significant changes in the construction of the ballast water management system must be reported to both the MPA and Lloyd's Register.

   2.5 The manufacturer must take reasonable measures to ensure that the operator of the system is trained & familiar with the operation of the system and is capable of operating and maintaining the system in accordance with the operating manual.

   2.6 If the manufacturer fails to comply with any condition of this Type Approval Certificate, the MPA may, at any time, suspend, revoke or withdraw this Type Approval Certificate.

Lloyd's Register
Sahan Abeysekara
Southampton GTC Office Office
Lloyd's Register EMEA

S. Abeysekara
Engineering Systems
Marine Technology & Engineering Services
Lloyd's Register EMEA

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ANNEX 2

SUMMARY OF THE LAND BASED AND SHIPBOARD TEST RESULTS FOR THE TYPE APPROVAL CERTIFICATE FOR THE SEMB-ECO LUV 500 BALLAST WATER MANAGEMENT SYSTEM

DHI

Land Based Testing of the Semb - Eco Ballast Water Treatment System

Final Report

For the avoidance of doubt, any reference to the "Semb-Eco Ballast Water Treatment System" or "BWTS" wherever appearing in this report, refers to the "Semb-Eco LUV 500" Ballast Water Management System.

Singapore Office
BT
Lloyd's Register Asia
Lloyd's Register

Sembawang Shipyard Pte Ltd

Final Report

May 2014

The expert in WATER ENVIRONMENTS

Executive Summary

The Semb-Eco Ballast Water Treatment System (BWTS) is a non-chemical system whereby ballast water treatment is achieved through a two-stage process. It uses filtration and LED amalgam UV (L-UV) to treat ballast water incorporating biofouling control (BFC).

Land based testing of the Semb-Eco Ballast Water Treatment System was conducted during the period of December 2013 – March 2014, following the principles of *Guidelines for approval of ballast water management systems (G8)* - Resolution MEPC.174(58).

The land based testing was carried out at the DHI Ballast Water Technology Innovation Centre in Singapore under challenging tropical water conditions, namely marine water and brackish water conditions with water temperatures around 30 °C. Two (2) day holding period was applied to test Semb – Eco Ballast Water Treatment System instead of 5 days recommended by IMO due to the high water temperature. Comparability of Test Challenge at Different Tank Holding Times (2 days vs 5 days) was carried out before the official initiation of land based test witnessed by Lloyd's Register and MPA Singapore The results confirmed that shorter hold times is in fact a greater challenge on ballast water treatment systems with respect to meeting the D-2 discharge standards.

The DHI Ballast Water Technology Innovation Centre in Singapore is a third party independent test facility with no interest, intellectual or financial, in the performance success of treatment systems being verified. The aim is to replicate realistic tropical test conditions with high biological activity and diversity.

A total of ten consecutive test cycles using 500m³/h BWTS units were carried out, five each under marine water and brackish water conditions. The results proved that the ballast water treatment system operates reliably, efficiently and effectively in meeting the D-2 discharge requirements under challenge water quality conditions for the required two salinities respectively.

No active substances were detected from discharged water. As such, the land-based tests carried out under challenging tropical water conditions have shown that the Semb – Eco BWTS function well and is efficient in meeting the D-2 discharge standard.

1 Introduction

For a Ballast Water Management System (BWMS) to receive type approval, the 2004 International Convention for the Control and Management of Ships' Ballast Water and Sediment (IMO, 2004) requires the BWMS to undergo rigorous testing according to the principles laid down in Resolution MEPC.174(58) (G8) and MEPC.169(57) (G9). This is to ensure that the BWMS approved by an administration is capable of meeting the ballast water D-2 discharge standard (MEPC G8) in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health.

The DHI Ballast Water Technology Innovation Centre in Singapore is a third party independent test facility aiming at providing stakeholders such as shipping lines, technology developers, regulators and class societies with independent and credible treatment and operational performance data of ballast water treatment systems under realistic conditions in seawater, brackish water and freshwater. DHI has no interest, intellectual or financial, in the performance success of treatment systems being verified.

The objective of the current study was to perform land-based testing of the Semb - Eco Ballast Water Treatment System to document efficacy and performance according to IMO Guidelines G8, MEPC.174 (58). The current report only covers data and results of relevance to Guidelines G8, MEPC.174 (58) for Final Approval.

4 Experimental Design

4.1 Phasing of the Study

The verification testing of the Semb - Eco BWTS consisted of two test phases:

1. Commissioning Test
2. Biological Efficacy (BE) Testing (G8)

4.2 Schedule of the Testing Programme

The testing programme was initiated on the 3rd Dec 2013 and completed on 28th Mar 2014. Ten (10) test cycles have been completed in total of which:

- 5 test cycles have been completed under brackish water conditions
- 5 test cycles have been completed under marine water conditions

4.3 Commissioning Testing

During the first phase, the treatment system was subjected to commissioning tests to validate that the system was integrated successfully into the test facility and could be operated according to specifications. The commission tests were carried out by Semb - Eco personals with DHI assistance. The results showed that the Semb – Eco BWTS functioned well under different challenge water conditions.

4.4 Biological Efficacy Testing

4.4.1 Test Cycle Design

After successful commissioning tests, the test facility performed the biological efficacy (BE) testing of the Semb - Eco BWTS under two salinity regimes and challenging test water quality to validate that the system is able to meet the discharge standards of the IMO D-2 regulation. The test was assessed for biological treatment efficacy and success or failure to meet the D-2 standards on the average discharge was recorded and documented. One test cycle from brackish water cycle was selected for analysis of disinfection by-products.

The test cycles had duration of two days and included the following activities:

1. Filling of Primary Tank;
2. Achievement and control of test water quality;
3. Treatment, sampling and transfer of test water to Test Tank;
4. Sampling and transfer of control water to Control Tank;
5. Cleaning of pipes and sampling systems;
6. Storage of treated test water and control water under gentle agitation;
7. Discharge, treatment, and sampling of water from Test Tank;
8. Discharge and sampling of water from Control Tank.
9. Cleaning of tanks, pipes and sampling systems.

4.4.2 Achievement of Test Water Quality

Test water was pumped into the primary tank by use of a Grundfos Paco seawater intake pump (30kW with a capacity of 250 m³/h).

According to IMO G8 guidelines, the land based test was conducted at two different salinities under the test water quality described in Table 4.1 and Table 4.2. The current study involves five brackish waters (21-22 PSU) and five marine waters (above 32 PSU) test via either dilute sea water with de-chlorinated tap water or by adding salt (sodium chloride) to sea water drawn from the Pandan Estuary. The latter has a typical salinity range of 27-31 PSU.

Table 4.1 The IMO G8 minimum requirements for challenge water quality (salinity, DOC, POC, TSS) and selected target for the current study

Parameter	Brackish water range (3-32 PSU)		High salinity range (>32 PSU)	
	G8	Target	G8	Target
Salinity, PSU	3-32	22	>32	33
Dissolved organic carbon (DOC) mg/L	>5	7	>1	2.5
Particulate organic carbon (POC) mg/L	>5	7	>1	2.5
Total suspended solids (TSS) mg/L	>50	70	>1	10.0

Table 4.2 The IMO G8 minimum requirements for test water quality (biological parameters)

Parameter	Total concentration	Comments
Organisms ≥ 50 µm	≥ 10^5 organisms/m^3	At least 5 species from at least 3 different phyla/divisions
Organism size: ≥ 10 µm - < 50 µm	≥ 10^3 cells/mL	At least 5 species from at least 3 different phyla/divisions
Heterotrophic bacteria	≥ 10^4 CFU/mL	Not further defined

The temperature of test water followed natural variations in Singapore and was within the range of 25 °C – 35 °C and organism concentrations were to adhere to the IMO G8 requirements in Table 4.2.

Depending on the weather conditions and time of the year, the water quality at the above location might naturally fulfil the required chemical and biological water quality criteria. In this case, the water was not altered.

Before the start of the test, an aggregated sample taken from a number of sampling points located throughout the primary tank was analysed for test water quality and organism concentration.

If water quality parameters were below minimum requirements, surrogate materials such as; lignosulfonate (DOC), corn flour (POC) or kaolin (TSS) - were added to the challenge water through the additional 1 m³ conical tank, the "dosing tank".

Usually, the concentrations of the 10 µm to < 50 µm organisms in the Primary Tank were below minimum requirements. Thus, cultured organisms of two sources were added routinely. Natural water samples from the river and monoculture of *Tetraselmis suecica* were cultured under optimal conditions of light, nutrients and mixing to reach the high density of natural assemblages.

In this way, a mixed culture containing both organisms naturally present in Pandan Estuary at the time of collection and cultured *Tetraselmis suecica* was prepared and dosed directly into the flow during the transfer of water to the Water Holding Tank to augment the ≥10 - <50 µm organism size class concentration. Cultured organisms were dosed to reach a final concentration in the intake water around 2,500 - 3,500 cells/ml

When the concentrations of organisms ≥ 50 µm were below minimum requirements, *Artemia salina* was dosed into the challenge water. *Artemia* are crustaceans commonly used as live prey in aquaculture. Sold as cysts or eggs, these can hatch into nauplii within 48 hours under optimal conditions. In the current study, *Artemia* were put under optimal hatching conditions of light and bubbling 48h prior to test initiation to allow the cysts to hatch into nauplii.

The concentration of heterotrophic bacteria in the Pandan Estuary typically exceeds the required level of ≥ 10^4 cfu ml^{-1}; hence no additional dosing of bacteria was carried out.

4.4.3 Sequence of Ballasting Operations

For every test cycle, the sequence of operations was as follows:

1. At least 200 m^3 of test water was pumped at a rate of 500 m^3/h and a pressure of 2.5 Bar from the Primary Tank through the Semb – Eco BWTS into the Test Tank.
2. At least 200 m^3 of test water was pumped at a rate of 500 m^3/h and a pressure of 2.5 Bar from the Primary Tank into the Control Tank bypassing the BWTS.
3. The piping and sampling systems were cleaned

During ballasting, flow rates (inflow and filter back flush), pressure (before and after BWTS), pH, temperature, Dissolved oxygen, conductivity and power consumption were monitored using an online monitoring and data logging system. Samples for documentation of water quality before and after treatment were collected by use of sampling points SP1, SP2 and SP3, respectively.

4.4.4 Storage of Test Water and Control Water

The test and control water was stored for 2 days (48 hours ± 10%) in the ballast tanks with gentle agitation. During storage, a number of biological, physical and chemical phenomena will take place. Of specific interest to the current study is the fact that it will be carried out in a tropical environment at approximately 30 °C. The high temperature will influence most of these phenomena such as:

The treatment systems chances of success may be improved in tropical climate due to:

- Lower biological challenge of organisms 10-50 µm due to more extensive grazing from zooplankton and micro-zooplankton

The treatment systems chances of success may be reduced in tropical climate due to:

- Faster regrowth of microorganisms
- Faster production of eggs from zooplankton
- Faster hatching of eggs from zooplankton

The test facility's chance of performing valid tests with sufficient viable organisms at discharge of the control tank is significantly reduced in tropical climate due to:

- Faster grazing by larger zooplankton on phytoplankton
- Faster grazing of phytoplankton by micro-zooplankton

To meet the G8 requirements of comparability to other systems tested under colder climates, the holding time in DHI Singapore Facility was reduced to two days and this issue was recognized by MEPC 63 and in MEPC 63/WP.7 (BWRG, 2012). A preliminary study regarding comparing test challenge at different tank holding times (2 days vs 5 days) was carried out before the official initiation of land based test with witness from Lloyd's Register and MPA Singapore. The results (Appendix H) confirmed that shorter hold time is in fact a greater challenge for the ballast water treatment systems with respect to meeting the D-2 discharge standards.

4.4.5 Deballasting Operations and Neutralization of Test Water.

For every test cycle, the sequence of operations was as follows:

1. Test water contained in the Test Tank was pumped out at 500 m³/h at 2.5 Bar into the Semb – Eco BWTS for further treatment before discharging into the Pandan River.
2. Untreated test water was pumped out at 500 m³/h at 2.5 Bar into the Pandan River;
3. The Test Tank, piping and sampling systems were cleaned.

During de-ballasting, flow rate, pressure (before and after BWTS), pH, temperature, dissolved oxygen, conductivity and power consumption were monitored using the online monitoring and data logging system.

Samples for documentation of water quality were collected by use of SP3 (for treated water) and SP2 (for untreated water).

4.4.6 Sampling Points

The piping system connecting the Primary Tank and the Control and Test Tanks is equipped with three sampling points (SP's). Water is sampled during the complete pumping duration to give a representative flow-integrated sampling. Each sampling port consists of four isokinetic sampling ports equipped with diaphragm valves for control of flow rate during sampling. All sample ports are running continuously for time proportional integrated sampling as well as grab sampling for specific parameters.

Triplicate samples will be collected for verification of the G8-D2 requirements according to the sampling schemes described in Section 4.4.7

The samples will be stored in thermo boxes after the time of collection and during transport to the environmental laboratory at DHI Singapore until handling of the samples in the laboratory.

4.4.7 Sampling Schemes

Sampling volumes have been set according to the minimum volumes set forth in the G8 Guidelines. The sample volumes applied are summarised in the following sections.

The types and locations for measurements in each category are summarised in Table 4.3.

Table 4.3 Challenge test validation criteria by location

Parameter	Intake	Inlet to test tank after treatment	Discharge from control tank to sea	Discharge from treatment tank to sea
Time	Day 0	Day 0	Day 2	Day 2
	Ballasting Operations			
Volume	X	X	X	X
Pressure	X	X	X	X
Flow	X	X	X	X
Power consumption		X		X
	Water Quality			
Temperature, Salinity, Turbidity, pH, DO, TSS, DOC, POC, UV-T	X	X	X	X
	Biological Diversity and Concentrations			
Viable organisms/m^3; ≥50 µm	X	X	X	X
Viable organisms/ml; ≥10 and <50 µm	X	X	X	X
Microorganisms/ml; Heterotrophic bacteria; Coliform bacteria; *E. coli*; Enterococci and *Vibrio cholera*	X	(X)*	X	X

**Only heterotrophic bacteria.*

4.4.7.1 Treatment of test water and control water

Table 4.4 Sampling of control water (SP1) and test water prior to treatment in BWTS (SP1)

Parameter	Volume collected	No. of field replicates	No. of lab replicates	Sampling SOP No.	Analysis by
Organisms, ≥ 50 µm	20 L	3	1-3	ETD-BWTIC-SOP-S02	DHI
Organisms, ≥10 - <50 µm	10 L	3	1-3	ETD-BWTIC-SOP-S02	DHI
Coliform bacteria, *E. coli*, Enterococci and *Vibrio cholera*	500 mL	3	1	ETD-BWTIC-SOP-S02	Setsco
Heterotrophic bacteria	2 X 100 mL	3	1	ETD-BWTIC-SOP-S02	Setsco
TSS	500 mL	3	1	ETD-BWTIC-SOP-S02	DHI
DOC/POC, UV-T	500 mL	3	1	ETD-BWTIC-SOP-S02	DHI
Temperature, pH, DO, salinity, turbidity,	On site/online	3/1	-	ETD-BWTIC-SOP-S02	DHI

Table 4.5 Sampling of test water after first treatment in the BWTS (SP3)

Parameter	Volume collected	No. of field replicates	No. of lab replicates	Sampling SOP No.	Analysis by
Organisms, ≥ 50 µm	1000 L	3	1-20	ETD-BWTIC-SOP-S02	DHI
Organisms, ≥10 - <50 µm	10 L	3	1-3	ETD-BWTIC-SOP-S02	DHI
Phytoplankton Most Probable Number (MPN) for viability	100 mL	3	1	ETD-BWTIC-SOP-S02	DHI
Coliform bacteria, *E. coli*, Enterococci and *Vibrio cholera*	500 mL	3	1	ETD-BWTIC-SOP-S02	Setsco
Heterotrophic bacteria	2 X 100 mL	3	1	ETD-BWTIC-SOP-S02	Setsco
TSS	500 mL	3	1	ETD-BWTIC-SOP-S02	DHI
DOC/POC, UV-T	500 mL	3	1	ETD-BWTIC-SOP-S02	DHI
Temperature, pH, DO, salinity, turbidity	On site/online	3/1	-	ETD-BWTIC-SOP-S02	DHI

Table 4.6 Sampling of control water after stored 2 days in control tank prior to discharge (SP2)

Parameter	Volume collected	No. of field replicates	No. of lab replicates	Sampling SOP No.	Analysis by
Organisms, ≥ 50 µm	1000 L	3	1-20	ETD-BWTIC-SOP-S02	DHI
Organisms, ≥10 - <50 µm	10 L	3	1-3	ETD-BWTIC-SOP-S02	DHI
Phytoplankton Most Probable Number (MPN) for viability	100 mL	3	1	ETD-BWTIC-SOP-S02	DHI
Coliform bacteria, *E. coli*, Enterococci and *Vibrio cholera*	500 mL	3	1	ETD-BWTIC-SOP-S02	Setsco
Heterotrophic bacteria	2 X 100 mL	3	1	ETD-BWTIC-SOP-S02	Setsco
TSS	500 mL	3	1	ETD-BWTIC-SOP-S02	DHI
DOC/POC, UV-T	500 mL	3	1	ETD-BWTIC-SOP-S02	DHI
Temperature, pH, DO, salinity, turbidity	On site/online	3/1	-	ETD-BWTIC-SOP-S02	DHI

4.4.8 Methods for Measuring Parameters

4.4.8.1 Verification of Efficacy

Plankton Analysis – Organisms ≥ 50 µm

The organisms ≥50 µm in minimum dimension are typically dominated by mesozooplankton (rotifers, crustaceans, molluscs, worms). The numbers of live organisms in the group >50 µm will be determined on the basis of mobility and morphology and by using the vital stain Neutral Red. The assessment of viability will be performed only after treatment (Day 0) and on discharge samples (control and treated) taken on Day 2 (to assess if discharge standards are met). Intake samples will be preserved in Lugol's solution and enumerated in the laboratory and all intact organisms will be counted as it is assumed that at intake all intact organisms are viable. The major taxonomic groups present in all samples will be noted. The specific methodologies applied are described in SOP No. ELD-SOP-PA-001.

Plankton analysis – organisms ≥ 10 µm - <50 µm

The viable organisms in the range ≥10 - <50 µm are typically composed of phytoplankton and micro-zooplankton. The viability of these organisms is assessed by vital staining and fluorescence microscopy. The assessment of viability will be performed only on samples after treatment (Day 0), and on discharge (Day 2) as it is assumed that at intake all intact organisms are viable. The major taxonomic groups present in all samples will be noted. The specific methodologies applied are described in SOP No. ELD- SOP-PA-002.

The MEPC G8 Guidelines for the approval of BWTS /1/ define viable organisms as "organisms and any life stages thereof that are living" (Section 3.12). There is no commonly accepted criterion to determine the death of algae. Applying vital staining as the sole method for the performance evaluation of BWTS is insufficient.

For this reason, a combination of two methods will be applied for the performance evaluation of the BWTS in the present land-based test:

- Vital staining and fluorescence microscopy counting
- Most probable number (MPN) analysis

The analyses of MPN of algae provide results that are related to ability of the organisms to establish and reproduce in the environment. Conducting a weight-of-evidence analysis which includes the results of both of the above mentioned methods is considered the most reliable procedure for the performance evaluation of the BWTS.

In addition the MPN analysis will provide additional proof of the viable living conditions in the control tank – despite eventual low microscopic counts of organisms in the size class ≥10 - <50 µm due to heavy grazing activity by zooplankton under tropical test conditions as the MPN method includes phytoplankton smaller than 10 µm – and can therefore be used as an additional validity criteria.

It is well known that for UV based systems, the vital staining and fluorescence microscopy counts at discharge tends to overestimate the number of viable organisms. A combination of the microscopic counts and MPN therefore is used to calculate the final number of viable organisms at discharge. The calculation is done as follows:

Viable organisms (10-50 µm) = MPN + Count (non MPN growing organisms)

Where "Count (non MPN growing organisms)" is the count of organisms that have not been documented to be able to grow in the MPN culture medium (mainly heterotrophic organisms)

For all phytoplankton samples (10-50 µm), both CMFDA and MPN methods are applied for viable counting and both values are reported in the appendix F. The same trend was repeatedly observed (e.g., sharp decrease for test cycle while a steady slope for control cycle) for 10 test cycles, which means the MPN method is well supported by CMFDA method. Therefore, only MPN values were used in the Result and Discussion section as it can provide more accurate information regarding the viability of organism upon discharge while the CMFDA count always reported fault positive values. This has been illustrated in the QAPP and approved by class society (Lloyd's Register).

DHI personnel will collect all the samples for verifying the requirements to the biological parameters in the influent test water and the effluent test water. The specific sampling methodologies applied are described in SOP No. ETD-BWTIC-SOP-S02 for biological parameters.

The samples for determining counts of viable organisms will be transported in thermo boxes as described in SOP No. ETD-BWTIC-SOP-S02 and analysed in DHI's laboratory within 6 hours after sampling.

All microbiological parameters will be analysed by Setsco. An overview of the microbial analyses carried out is provided in Table 4.7.

Table 4.7 Analyses of microbiological parameters carried out by Setsco.

Parameter	Unit	Detection limit	Method
Heterotrophic bacteria	cfu/ml	1	APHA : Pt 9210 B (adopted to use Marine Agar 2216)
Total Coliform bacteria	cfu/100 ml	1	APHA : Pt 9222 B
E. Coli	cfu/100 ml	1	APHA : Pt 9222G
Enterococci	cfu/100 ml	1	APHA:Pt9230C
Vibrio cholera	cfu/100 ml	1	APHA : Pt 9260H

4.4.8.2 Physical and Chemical Analyses

The physical and chemical analyses included on-site measurements (Analysis package 1), analyses carried out in laboratory (Analysis package 2) and disinfection by-products (DBPs).

Analysis package 1 (on-site measurements):

- pH (online and discrete in 1 aggregated sample)
- Temperature (online and discrete in 1 aggregated sample)
- Salinity (online and discrete in 1 aggregated sample)
- Turbidity (online and discrete in 1 aggregated sample)
- Dissolved oxygen (online and discrete in 1 aggregated sample)
- Pressure (online)
- Flow rate (online)
- Volume (online)
- Power consumption (online)

Analysis package 2 (analysed at DHI Environmental Laboratory):

- TSS
- POC
- DOC
- NH_3-N, NO_3-N, and NO_2-N (only analysed in SBOBM05)
- UV-T

DHI Environmental Laboratory is accredited by Singapore Accreditation Council and all parameters in the Analysis package 2 were tested according to ISO 17025.

The specific on site measurements are described in SOP No. ETD-BWTIC-SOP-TF03 for online measurements and SOP No. ETD-BWTIC-SOP-S02 for on-site measurements.

The water samples for DPBs analysis were collected from the fifth brackish water test cycles and sent to external laboratory for analysis. The parameters to be analysed is listed as follows:

Table 4.8 Analyses of disinfection by-products performed by TÜV SÜD PSB

Compound	Detection limit (µg/l)	Method
Trihalomethanes (TTHM)	1	USEPA 8260C
Trichloromethane	1	USEPA 8260C
Dichlorobromomethane	1	USEPA 8260C
Dibromochloromethane	1	USEPA 8260C
Tribromomethane	1	USEPA 8260C
Bromate	5	Derivatization, GCMS
Halogenated acetic acids (HAA)	1	USEPA 552
Monochloroacetic acid (MCAA)	10	USEPA 552
Dichloroacetic acid (DCAA)	2	USEPA 552
Trichloroacetic acid (TCAA)	2	USEPA 552
Monobromoacetic acid (MBAA)	1	USEPA 552
Dibromoacetic acid (DBAA)	2	USEPA 552
Tribromoacetic acid (TBAA)	5	USEPA 552
Bromochloroacetic acid (BCAA)	2	USEPA 552
Dibromochloroacetic acid (DBCAA)	5	USEPA 552
Dichlorobromoacetic acid (DCBAA)	5	USEPA 552
Dichloracetonitrile	1	USEPA 551
Dibromoacetonitrile	1	USEPA 551
Bromochloroacetonitrile	1	USEPA 551
Monochloroamine	100	APHA 4500 -Cl
Trichloropropane	1	USEPA 551

The parameters in Analysis package 2 were measured at intake (Day 0), after treatment (Day 0), in-tank (Day 1), and on discharge after treatment (Day 2). Copies of the test report from TÜV SÜD PSB are attached in Appendix D. No active substances were detected from discharged water.

5 Validity Criteria

A biological efficacy test cycle will be regarded as valid, if:

- The test facility equipment functioned properly;
- The average test water quality did not deviate significantly from the requirements
- A total volume of minimum 200 m³ (each) has been transferred to the Test Tank and Control Tank respectively
- The average flow rate at both ballasting and de-ballasting was higher than 200 m³/h.
- The average results of the untreated test water (control) at the time of discharge (Day 2) are higher than 10 times the values in regulation D-2.1

Table 5.1 Primary validity criteria for control discharge samples.

Organism category	Criteria
Organisms ≥ 50 µm	>100 organisms/m^3
Organism size: ≥10 µm - < 50 µm	>100 organisms/mL*

**Measured using MPN analysis.*

6 Success Criteria

A biological efficacy treatment test cycle is deemed successful if:

1. It is valid in accordance with the validity criteria described above
2. At discharge, the average density of viable organisms greater than or equal to 50 µm in minimum diameter in the replicate samples is less than 10 viable organisms per m^3
3. At discharge, the average density of viable organisms less than 50 µm and greater than or equal to 10 µm in minimum diameter in the replicate samples is less than 10 viable organisms per mL
4. At discharge, the average density of *Vibrio cholerae* is less than 1 cfu per 100 mL
5. At discharge, the average density of *E. coli* in the replicate samples is less than 250 cfu per 100 mL
6. At discharge, the average density of Intestinal *Enterococci* in the replicate samples is less than 100 cfu per 100 mL

Table 6.1 Success criteria for test water at discharge (IMO D2 requirements)

Organism category	Criteria
Organisms ≥ 50 µm	<10 cells/m^3
Organism size: ≥10 µm - ≤ 50 µm	<10 cells/mL
Toxicogenetic *Vibrio cholera*	<1 cfu/100 mL
Escherichia coli	<250 cfu/100 mL
Intestinal *Enterococci*	<100 cfu/100 mL

7 Results and Discussion

A total of ten test cycles were carried out under Brackish Water conditions (< 22 PSU) and marine water conditions (>32 PSU) and all the test cycles were deemed valid and successful according to IMO G8 minimum requirements. The results of challenge water quality parameters and discharge water quality parameters are summarized and presented in this section.

7.1 Brackish Water Test Result

7.1.1 Challenge Water Quality

7.1.1.1 Dissolved and Particulate Organic Matter

The concentration of Dissolved Organic Matter (DOC) was augmented with commercial available Lignosulfonate (Lignin) and the concentration of Particulate Organic matter (POC) was augmented by addition of commercial available food grade corn flour to achieve target concentration of DOC and POC of 7 mg/L.

The concentration of total suspended solids of the challenge water was achieved by adding commercial kaolin clay in order to reach the target value of 70 mg/L.

Table 7.1 Achieved test water quality (dissolved and particulate content) for brackish water test

Parameter	Units	G8 Requirements	Test Cycle	Intake Test	Intake control Test
DOC	mg/L	> 5	SBOBW1	7.19	6.77
			SBOBW2	6.59	6.34
			SBOBW3	7.17	7.28
			SBOBW4	8.23	8.22
			SBOBW5	7.75	7
POC	mg/L	> 5	SBOBW1	8.51	8.17
			SBOBW2	9.38	9.1
			SBOBW3	8.74	9.95
			SBOBW4	6.51	6.71
			SBOBW5	6.82	8.57
TSS	mg/L	> 50	SBOBW1	77.2	81.2
			SBOBW2	69.6	73.6
			SBOBW3	70	69.4
			SBOBW4	69.6	70.1
			SBOBW5	72.2	69

7.1.1.2 Biological Parameters

All test cycles met the intake requirements of concentration and diversity for organisms as stipulated in IMO G8 guidelines. The diversity of organisms' ≥ 50µm and organisms within the range of ≥ 10 – 50 µm were summarized and attached to the appendix G. For all phytoplankton samples (10-50 µm), both CMFDA and MPN methods are applied for viable counting and both values are reported and presented in the appendix F

Table 7.2 Achieved test water quality (biological parameters) for brackish water test

Parameter	Units	G8 requirements		Test Cycle	Intake Test	Intake Control
		Concentration	Diversity			
Organisms ≥ 50 µm	/m^3	≥ 100,000	At least five species from at least three different phyla/divisions	SBOBW1	127065	129167
				SBOBW2	116957	120667
				SBOBW3	106667	225000
				SBOBW4	280000	193333
				SBOBW5	360000	410000
Phytoplankton MPN	ml^{-1}	≥ 1,000	At least 5 species from at least 3 different phyla/divisions	SBOBW1	2333	>9200
				SBOBW2	>9200	3667
				SBOBW3	>9200	16000
				SBOBW4	2900	4133
				SBOBW5	1743	2900
Heterotrophic bacteria	CFU/ml	≥ 10,000	NA	SBOBW1	294000	266667
				SBOBW2	292000	323000
				SBOBW3	290000	415667
				SBOBW4	238000	277333
				SBOBW5	1433333	1596667

Usually the concentrations of the organisms 10 µm - < 50 µm in the primary tank were below minimum requirements. In order to meet the target concentration, cultured organisms of two sources were added routinely. When the concentrations of Organisms ≥ 50 µm were below minimum requirements, *Artemia salina* was dosed into the challenge water in order to meet the intake requirements as stipulated under G8 guidelines.

7.1.1.3 Environmental Parameters

The environmental parameters of the intake water was measured on site and presented in Table 7.3.

Table 7.3 Environmental parameters taken during intake for brackish water test

Parameter	Units	Test Cycle	Intake Test	Intake control
pH	-	SBOBW1	8.09	8.1
		SBOBW2	7.68	7.7
		SBOBW3	8.14	8.13
		SBOBW4	8.21	8.25
		SBOBW5	8.27	8.34
Temperature	°C	SBOBW1	28.3	29
		SBOBW2	27.8	28.3
		SBOBW3	28.3	28.8
		SBOBW4	27.2	27.4
		SBOBW5	27.8	27.8
Salinity	PSU	SBOBW1	21.6	21.8
		SBOBW2	21.9	21.9
		SBOBW3	21.9	21.9
		SBOBW4	21.7	21.7
		SBOBW5	21.2	21.3
DO	mg/L	SBOBW1	7.81	7.37
		SBOBW2	7.96	8.13
		SBOBW3	8.01	7.8
		SBOBW4	6.78	6.75
		SBOBW5	6.52	6.4
Turbidity	NTU	SBOBW1	29.5	31.5
		SBOBW2	28.1	33
		SBOBW3	29	29.1
		SBOBW4	27.3	24.8
		SBOBW5	28.6	30.7
UV-T (%)	NTU	SBOBW1	63.3	64.4
		SBOBW2	65.5	64
		SBOBW3	65.5	64.4
		SBOBW4	63.6	62.2
		SBOBW5	63.6	62.6

According to IMO guidelines the salinity for brackish water was in the range of 3-32 PSU. For Semb-Eco BWTS, the salinity was maintained in the range of 21-22 PSU. The temperature of the test water followed the natural conditions of 25-30 °C

7.1.1.4 Nutrient Analysis

The additional water samples were taken from the fifth brackish water test cycle for analysis of the nutrient (NH_3-N, NO_2-N, and NO_3-N) and disinfection by-products (DPBs) in order to confirm that the treated water did not contain any toxic substances upon discharging. The analysis results for nutrient levels at intake were summarized as follows:

Table 7.4 Nutrient analysis for the fifth brackish water test

Parameter	Intake test	Intake control test
NH_3-N(mg/l)	0.03	0.03
NO_3-N (mg/l)	0.26	0.33
NO_2-N (mg/l)	0.02	0.02

7.1.1.5 Operational Parameters for Ballasting

During ballasting the DHI Facility Supervisor monitored the operation of the Semb-Eco BWTS to verify that the system 4020was operated according to specifications. The main operational parameters are summarised in Table 7.5.

Table 7.5 Operational parameters for ballasting test tank

Test No.	Flow rate (m^3/h)	Back flush rate (m^3/h)	Net flow rate (m^3/h)	Relative back flush (m^3/m^3)	Pressure in (bar)	Pressure out[1] (bar)	Pressure Loss (bar)	Water Volume in Test Tank (m^3)
SBOBW1	500	63.1	436.9	0.144	2.4	1.7	0.7	212.7
SBOBW2	499.8	63.1	436.7	0.144	2.4	1.7	0.7	209.1
SBOBW3	499.9	66.7	433.2	0.154	2.4	1.7	0.7	214.4
SBOBW4	500	63.2	436.8	0.145	2.4	1.7	0.7	214.9
SBOBW5	500	62.9	437.1	0.144	2.4	1.7	0.7	214.8

Table 7.6 Operational parameters for ballast control tank

Test cycle	Ballasting control tank	
	Flow rate (m^3/h)	Water Volume in Control Tank(m^3)
SBOBW1	500	213.5
SBOBW2	499.8	214.6
SBOBW3	499.9	211.6
SBOBW4	500	218.2
SBOBW5	500	216.8

7.1.2 Discharge Water Quality

7.1.2.1 Biological Parameters

After two days in the Water Holding Tank, the treated test water was discharged and samples were taken. The discharge results are presented in Table 7.7. The results presented show that the Semb-Eco Ballast Water Treatment System succeeded in achieving the D-2 discharge standards at this land based testing scale. Both the organism size classes ≥ 50 µm and ≥10 - < 50 µm met the D-2 discharge standards. The *E coli*, Enterococcus group, total Coliform and *Vibrio cholera* concentrations also met the discharge standards.

Table 7.7 Biological parameters for brackish water discharge test cycles

Parameter	Units	Test Cycle	D-2 Standards	Discharge Test	Discharge Control	D-2 Standards Achieved?
Organisms ≥ 50 µm	/m^3	SBOBW1	< 10	5	44000	Yes
		SBOBW2		7	59333	Yes
		SBOBW3		3	56000	Yes
		SBOBW4		1	23500	Yes
		SBOBW5		3	157667	Yes
Phytoplankton MPN	ml^{-1}	SBOBW1	< 10	<3.18	>1661	Yes
		SBOBW2		4.44	847	Yes
		SBOBW3		0.91	>371	Yes
		SBOBW4		<4.18	248	Yes
		SBOBW5		<1.88	254	Yes
E. coli		SBOBW1	< 250	<1	<1	Yes
		SBOBW2		<1	<1	Yes
		SBOBW3		<1	<1	Yes
		SBOBW4		<1	<1	Yes
		SBOBW5		<1	<1	Yes
Total Coliform		SBOBW1	< 1	<1	<1	yes
		SBOBW2		<1	<1	yes
		SBOBW3		<1	<1	yes
		SBOBW4		<1	<1	yes
		SBOBW5		<1	<1	yes
Enterococcus group		SBOBW1	< 100	<1	<1	yes
		SBOBW2		<1	<1	yes
		SBOBW3		<1	<1	yes
		SBOBW4		<1	<1	yes
		SBOBW5		<1	<1	yes
Vibrio cholerae		SBOBW1	< 1	ND	ND	yes
		SBOBW2		ND	ND	yes
		SBOBW3		ND	ND	yes

Parameter	Units	Test Cycle	D-2 Standards	Discharge Test	Discharge Control	D-2 Standards Achieved?
		SBOBW4		ND	ND	yes
		SBOBW5		ND	ND	yes

7.1.2.2 Environmental Parameters

Environmental parameters were measured on site during de ballasting operations and recorded and summarized as given below.

Table 7.8 Environmental parameters for brackish water discharge test cycles

Parameter	Units	Test Cycle	Discharge Test	Discharge Control
pH	-	SBOBW1	7.55	7.43
		SBOBW2	7.65	7.58
		SBOBW3	7.48	7.37
		SBOBW4	7.93	7.66
		SBOBW5	7.94	7.72
Temperature	°C	SBOBW1	28.7	29
		SBOBW2	27.9	28
		SBOBW3	27.1	27.2
		SBOBW4	27.6	27.4
		SBOBW5	27.7	28
Salinity	PSU	SBOBW1	21.8	21.6
		SBOBW2	22.2	22.1
		SBOBW3	21.5	21.7
		SBOBW4	21.7	21.7
		SBOBW5	21.2	21.3
DO	mg/L	SBOBW1	6.89	4.47
		SBOBW2	5.34	5
		SBOBW3	4.16	3.66
		SBOBW4	6.11	5.48
		SBOBW5	5.78	5.15
Turbidity	NTU	SBOBW1	2.24	2.82
		SBOBW2	2.3	1.21
		SBOBW3	1.55	2.5
		SBOBW4	2.94	1.85
		SBOBW5	2.28	2.3
UV-T (%)	NTU	SBOBW1	65.9	64.8
		SBOBW2	66.5	64.4
		SBOBW3	67.2	62.9
		SBOBW4	64.5	63.5

		SBOBW5	64.5	64.2

7.1.2.3 Operational Parameters for de Ballasting

During de-ballasting the DHI Facility Supervisor monitored the operation of the Semb-Eco BWTS to verify that the system was operated according to specifications. The main operational parameters are summarised in Table 7.9.

Table 7.9 Operational parameters for de ballasting test tank

Test No.	Flow rate (m^3/h)	Back flush rate (m^3/h)	Net flow rate (m^3/h)	Relative back flush (m^3/m^3)	Pressure in (bar)	Pressure out (bar)	Pressure Loss (bar)
SBOBW1	500	63.2	436.8	0.145	2.4	1.7	0.7
SBOBW2	499.8	63.6	436.2	0.146	2.4	1.7	0.7
SBOBW3	499.8	63.7	436.1	0.146	2.4	1.7	0.7
SBOBW4	500	63.6	436.4	0.146	2.4	1.7	0.7
SBOBW5	500	63.4	436.6	0.145	2.4	1.7	0.7

Table 7.10 Operational parameters (Flow rate) in deballasting control tank

Test cycle	Deballasting control tank
	Flow rate (m^3/h)
SBOBW1	500
SBOBW2	499.8
SBOBW3	499.9
SBOBW4	500
SBOBW5	500

7.1.3 Disinfection By-Products Analysis

The results of the disinfection by-products analysis for the fifth brackish water test cycle are presented in Table 7.11. Copies of the original test reports as received from TÜV SÜD PSB are attached in Appendix D.

Table 7.11 Analyses of disinfection by-products performed by TUV SUD PSB for fifth brackish water test

Compound	Detection limit (µg/L)	Intake /Test water (Day 0)	Treatment (Day 0)	Intake control (Day 0)	Test water (Day 1)	Control water (Day 1)	Discharge (Day 2)	Discharge control (Day 2)
Trihalomethanes (TTHM)	1	ND	ND	ND	ND	ND	ND	ND
Trichloromethane	1	ND	ND	ND	ND	ND	ND	ND
Dichlorobromomethane	1	ND	ND	ND	ND	ND	ND	ND
Dibromochloromethane	1	ND	ND	ND	ND	ND	ND	ND
Tribromomethane	1	ND	ND	ND	ND	ND	ND	ND
Bromate	5	ND	ND	ND	ND	ND	ND	ND
Halogenated acetic acids (HAA)	1	7	6	5	4	5	5	2
Monochloroacetic acid (MCAA)	10	ND	ND	ND	ND	ND	ND	ND
Dichloroacetic acid (DCAA)	2	3	3	2	12	3	3	ND
Trichloroacetic acid (TCAA)	2	ND	ND	ND	ND	ND	ND	ND
Monobromoacetic acid (MBAA)	1	1	ND	ND	ND	ND	ND	ND
Dibromoacetic acid (DBAA)	2	ND	ND	ND	ND	ND	ND	ND
Tribromoacetic acid (TBAA)	5	ND	ND	ND	ND	ND	ND	ND
Bromochloroacetic acid (BCAA)	2	3	3	3	2	2	2	2
Dibromochloroacetic acid (DBCAA)	5	ND	ND	ND	ND	ND	ND	ND
Dichlorobromoacetic acid (DCBAA)	5	ND	ND	ND	ND	ND	ND	ND
Dichloracetonitrile	1	ND	ND	ND	ND	ND	ND	ND

Results and Discussion

Compound	Detection limit (µg/L)	Intake /Test water (Day 0)	Treatment (Day 0)	Intake control (Day 0)	Test water (Day 1)	Control water (Day 1)	Discharge (Day 2)	Discharge control (Day 2)
Dibromoacetonitrile	1	ND	ND	ND	ND	ND	ND	ND
Bromochloroacetonitrile	1	ND	ND	ND	ND	ND	ND	ND
Monochloroamine	100	ND	ND	ND	ND	ND	ND	ND
Trichloropropane	1	ND	ND	ND	ND	ND	ND	ND

It should take note that several disinfection by-products (HAA, DCAA and BCAA) were identified from water samples. However, those DPBs should come from ambient sea water instead of generating from Semb – Eco BWTS since they appeared in the intake water sample as well. DHI test facility located within a shipyard where the sea water is contaminated due to shipping manufacturing activities.

7.2 Marine Water Test Result

7.2.1 Challenge Water Quality

7.2.1.1 Dissolved and Particulate Organic matter

As shown in Table 7.12, G8 intake requirements for DOC, POC and TSS were met. All results were above the target concentrations of 2.5, 2 and 10 respectively.

Table 7.12 Achieved test water quality (dissolved and particulate content) for marine water test

Parameter	Units	G8 requirements	Test Cycle	Intake Test	Intake Control Test
DOC	mg/L	> 1	SBOMW1	2.63	2.46
			SBOMW2	2.51	2.41
			SBOMW3	3.23	2.79
			SBOMW4	2.75	2.44
			SBOMW5	2.98	3.15
POC	mg/L	> 1	SBOMW1	2.7	3.08
			SBOMW2	2.96	3.51
			SBOMW3	2.29	2.67
			SBOMW4	3.1	3.81
			SBOMW5	3.10	3.56
TSS	mg/L	> 1	SBOMW1	15.6	16
			SBOMW2	15	18.1
			SBOMW3	14.9	16.3
			SBOMW4	20	24.1
			SBOMW5	17.4	18.6

7.2.1.2 Biological Parameters

Intake requirements for all organism groups were met for both concentrations and diversity. The different types of species under different phyla were identified and summarized in the appendix G.

Table 7.13 Achieved test water quality (biological parameters) for marine water test

Parameter	Units	G8 requirements		Test Cycle	Intake Test	Intake Control Test
		Concentration	Diversity			
Organisms≥ 50 µm	/m^3	≥ 100,000	At least five species from at least three different phyla/divisions	SBOMW1	370000	450000
				SBOMW2	426667	500000
				SBOMW3	423333	370000
				SBOMW4	307778	286667
				SBOMW5	390000	205000
Phytoplankton MPN	cells/ml	≥ 1,000	At least 5 species from at least 3 different phyla/divisions	SBOMW1	2167	2167
				SBOMW2	>4300	5600
				SBOMW3	1613	3900
				SBOMW4	3167	5167
				SBOMW5	4167	3900
Heterotrophic bacteria	CFU/mL	≥ 10,000	NA	SBOMW1	257333	255333
				SBOMW2	532667	284000
				SBOMW3	501667	451333
				SBOMW4	448333	125333
				SBOMW5	673333	283667

7.2.1.3 Environmental Parameters

The environmental parameters measured during ballasting operations for marine water cycles were recorded and tabulated as follows;

Table 7.14 Environmental parameters taken during intake (challenge/test water) for marine water test

Parameter	Units	Test Cycle	Intake Test	Intake Control Test
pH	-	SBOMW1	8.32	8.34
		SBOMW2	7.9	7.96
		SBOMW3	8.15	8.16
		SBOMW4	8.08	8.13
		SBOMW5	8.13	8.18
Temperature	°C	SBOMW1	26.8	27
		SBOMW2	27.8	27.8
		SBOMW3	28.1	28.8
		SBOMW4	28.3	28
		SBOMW5	26.7	28
Salinity	PSU	SBOMW1	33.2	33.3
		SBOMW2	33.7	33.7
		SBOMW3	33.3	33.3
		SBOMW4	33	32.9
		SBOMW5	33.3	33.3
DO	mg/L	SBOMW1	6.27	6.18
		SBOMW2	6.47	6.28
		SBOMW3	6.69	6.44
		SBOMW4	6.48	6.37
		SBOMW5	5.38	5.5
Turbidity	NTU	SBOMW1	5.44	6.73
		SBOMW2	6.68	7.11
		SBOMW3	7.17	7.24
		SBOMW4	10.43	13.3
		SBOMW5	4.61	5.62
UV-T	%	SBOMW1	86.1	87
		SBOMW2	86.8	87.2
		SBOMW3	84.5	85.2
		SBOMW4	86.5	86.7
		SBOMW5	83.9	84.3

According to IMO guidelines the salinity for marine water was >32 PSU. For Semb-Eco BWTS, the salinity was maintained around 33 PSU. The temperature of test water followed the natural conditions of 25-30 °C

7.2.1.4 Operational Parameters for Ballasting Test Tank

During ballasting the DHI Facility Supervisor monitored the operation of the Semb-Eco BWTS to verify that the system was operated according to specifications. The main operational parameters are summarised as follows;

Table 7.15 Operational parameters for ballasting test tank.

Test No.	Flow rate (m^3/h)	Back flush rate (m^3/h)	Net flow rate (m^3/h)	Relative back flush (m^3/m^3)	Pressure in (bar)	Pressure out (bar)	Pressure Loss (bar)	Water Volume in Test Tank (m^3)
SBOMW 1	500	62.3	437.7	0.142	2.4	1.7	0.7	212.2
SBOMW 2	500	62.6	437.4	0.143	2.4	1.7	0.7	211.6
SBOMW 3	500	62.6	437.4	0.143	2.3	1.7	0.6	211.0
SBOMW 4	500	62.5	437.5	0.143	2.4	1.7	0.7	212.9
SBOMW 5	500	62.7	437.3	0.143	2.4	1.7	0.7	213.6

The flow rate and volume of the control tank during ballasting operation was recorded and tabulated.

Table 7.16 Operational parameters for ballasting control tank

Test cycle	Ballasting control tank	
	Flow rate (m^3/h)	Volume (m^3)
SBOMW1	500	214.9
SBOMW2	500	233.1
SBOMW3	500	213.0
SBOMW4	500	214.7
SBOMW5	500	215.7

7.2.2 Discharge Water

7.2.2.1 Biological Parameters

Table 7.17 Discharge organism concentrations for marine water test

Parameter	D-2 Standards	Test cycle	Discharge	Discharge Control	D-2 Standards Achieved?
Viable organisms ≥ 50 µm	< 10	SBOMW1	0	52133	Yes
		SBOMW2	0.3	62333	Yes
		SBOMW3	0	20267	Yes
		SBOMW4	0.3	62000	Yes
		SBOMW5	6	58667	Yes
Phytoplankton MPN		SBOMW1	<0.18	609	Yes
		SBOMW2	<0.18	686	Yes
		SBOMW3	<3.18	1025	Yes
		SBOMW4	>0.36	343	Yes
		SBOMW5	<0.18	564	Yes
Enterococcus group	< 100	SBOMW1	<1	<1	Yes
		SBOMW2	<1	<1	Yes
		SBOMW3	<1	<1	Yes
		SBOMW4	<1	<1	Yes
		SBOMW5	<1	<1	Yes
E. coli	< 250	SBOMW1	<1	<1	yes
		SBOMW2	<1	<1	yes
		SBOMW3	<1	<1	yes
		SBOMW4	<1	<1	yes
		SBOMW5	<1	<1	yes
Total Coliform	_	SBOMW1	<1	<1	yes
		SBOMW2	<1	<1	yes
		SBOMW3	<1	<1	yes
		SBOMW4	<1	<1	yes
		SBOMW5	<1	<1	yes
Vibrio cholerae	< 1	SBOMW1	ND*	ND*	yes
		SBOMW2	ND*	ND*	yes
		SBOMW3	ND*	ND*	yes
		SBOMW4	ND*	ND*	yes
		SBOMW5	ND*	ND*	yes

After two days in the Water Holding Tank, the treated test water was discharged and samples were taken. The discharge results are presented in Table 7.13 The results presented show that Semb-Eco Ballast Water Treatment System succeeded in achieving the D-2 discharge standards at this testing scale for marine water. Both the organism size classes ≥ 50 µm and ≥10 - < 50 µm showed that discharge concentrations met the D-2 discharge standards. The *E.coli*, Enterococcus group, total Coliform and *Vibrio cholerae* concentrations also met the discharge standards.

7.2.2.2 Environmental Parameters

The water quality parameters taken throughout the discharge tests in marine water are presented in the Table 7.18.

Table 7.18 Water quality parameters recorded for marine water test

Parameter	Test cycle	Discharge	Discharge control
Turbidity (NTU)	SBOMW1	1.7	1.37
	SBOMW2	1.35	1.18
	SBOMW3	1.26	1.36
	SBOMW4	2.07	1.44
	SBOMW5	1.18	1.2
Temperature (°C)	SBOMW1	27.5	27.6
	SBOMW2	27.2	26.9
	SBOMW3	26.1	26.5
	SBOMW4	27.3	27.9
	SBOMW5	27.3	27.6
Salinity (PSU)	SBOMW1	33.3	33.3
	SBOMW2	33.7	33.7
	SBOMW3	33.2	33.2
	SBOMW4	33	33
	SBOMW5	33.3	33.3
DO (mg/L)	SBOMW1	5.74	5.26
	SBOMW2	5.88	5.48
	SBOMW3	6.04	5.44
	SBOMW4	6.02	5.3
	SBOMW5	5.62	5.4
pH (pH Units)	SBOMW1	8.13	8.06
	SBOMW2	7.81	7.68
	SBOMW3	8.1	8.02
	SBOMW4	7.94	7.91
	SBOMW5	8	7.91
UV-T (%)	SBOMW1	86.1	85.2
	SBOMW2	87.9	86.3
	SBOMW3	86.8	85.5
	SBOMW4	87.4	86.8
	SBOMW5	86.7	84.7

7.2.2.3 Operational Parameters for De Ballasting Test Tank

During de-ballasting the DHI Facility Supervisor monitored the operation of the Semb- Eco BWTS to verify that the system was operated according to specifications. The main operational parameters are summarised in Table 7.19

Table 7.19 Operational parameters for de ballasting test tank.

Test No.	Flow rate (m^3/h)	Back flush rate (m^3/h)	Net flow rate (m^3/h)	Relative back flush (m^3/m^3)	Pressure in (bar)	Pressure out (bar)	Pressure Loss (bar)
SBOMW1	500	62.9	437.1	0.144	2.4	1.7	0.7
SBOMW2	500	62.5	437.5	0.143	2.4	1.7	0.7
SBOMW3	500	62.8	437.2	0.144	2.4	1.7	0.7
SBOMW4	500	62.9	437.1	0.144	2.4	1.7	0.7
SBOMW5	500	62.9	437.1	0.144	2.4	1.7	0.7

Table 7.20 Operational parameters (Flow rate) in deballasting control tank

Test cycle	Deballasting control tank
	Flow rate (m^3/h)
SBOMW1	500
SBOMW2	500
SBOMW3	500
SBOMW4	500
SBOMW5	500

7.2.2.4 Power Consumption of Semb – Eco BWTS

The BWTS power consumption for ballasting & deballasting during 10 test cycles was recorded and listed in Table 7.21.

Table 7.21 Power consumption of Semb – Eco BWTS.

Test No.	Power consumed during ballasting (KW)				Power consumed during deballasting (KW)			
	BWTS System[1]	UV+BFC[2]	UV Rated Power[2]	BFC Rated Power[2]	BWTS System[1]	UV+BFC[2]	UV Rated Power[2]	BFC Rated Power[2]
SBOBW1	18.94	15.80	13.70	2.7	17.49	14.0	13.70	1.1
SBOBW2	18.73	15.80	13.70	2.7	17.19	14.0	13.70	1.1
SBOBW3	24.62[3]	15.80	13.70	2.7	17.11	14.0	13.70	1.1
SBOBW4	18.86	15.80	13.70	2.7	17.18	14.0	13.70	1.1
SBOBW5	18.24	15.80	13.70	2.7	17.23	14.0	13.70	1.1
SBOMW1	18.77	15.80	13.70	2.7	17.22	14.0	13.70	1.1
SBOMW2	18.53	15.80	13.70	2.7	17.23	14.0	13.70	1.1
SBOMW3	19.13	15.80	13.70	2.7	17.37	14.0	13.70	1.1
SBOMW4	18.61	15.80	13.70	2.7	17.30	14.0	13.70	1.1
SBOMW5	18.72	15.80	13.70	2.7	17.25	14.0	13.70	1.1
Average	18.73				17.26			

Note: 1 – data recored by DHI

2 – data provided by Semb – Eco

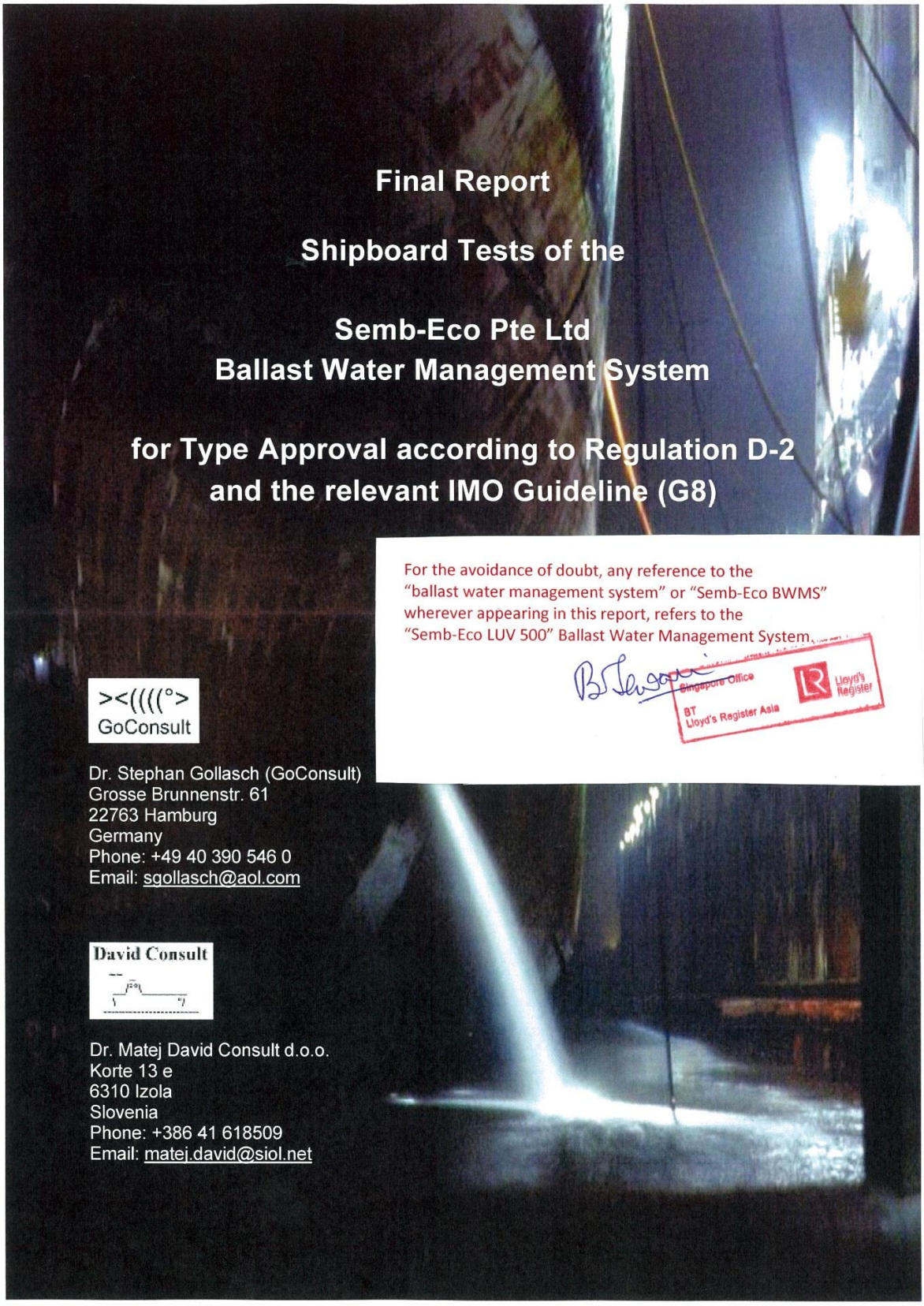
3 - The provisional filter backflush pump which is normally not required during ballast operation was accidently switched on by Semb – Eco and resulted in high power consuption in test cycle SBOBW3.

The other components (Filter, UPS and data providing instruments) consumed the remaining 3.4 KW according to the record from Semb – Eco.

8 Conclusions

A total of ten test cycles were carried out with Semb-Eco BWTS, five test cycles each under marine water and brackish water conditions. All test cycles meet the intake water criteria according to IMO G8 guideline and valid criteria for control tank discharge on day 2 according to D-2 discharge standard. Semb – Eco BWTS was successful in meeting the D-2 discharge standard for all organism classes in the 10 test cycles.

This land-based test carried out challenging tropical water conditions has proven that the Semb-Eco BWTS operates reliably, efficiently and effectively in meeting the D-2 discharge standard.



Final Report

Shipboard Tests of the

Semb-Eco Pte Ltd
Ballast Water Management System

for Type Approval according to Regulation D-2 and the relevant IMO Guideline (G8)

For the avoidance of doubt, any reference to the "ballast water management system" or "Semb-Eco BWMS" wherever appearing in this report, refers to the "Semb-Eco LUV 500" Ballast Water Management System.

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BT
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Final Report

Shipboard Tests of the

Semb-Eco Pte Ltd
Ballast Water Management System

for Type Approval according to Regulation D-2 and the relevant IMO Guideline (G8)

(January – August 2015)

Shipboard tests on board MV *PAC Suhail*

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14th September 2015

Table of Content

1. Introduction

The ballast water management system (BWMS) developed by Semb-Eco Pte Ltd (hereafter Semb-Eco), consists of filtration and UV.

To conduct the shipboard tests of the Semb-Eco BWMS the two independent ship board test facilities Gollasch Consulting (GoConsult) and Dr Matej David Consult d.o.o. (David Consult) formed a strategic partnership, which was formally recognised as the partnership GCDC – 'GoConsult David Consult'. The GCDC Quality Management Plan (QMP) and GCDC Quality Assurance Project Plan QAPP) were reviewed by Lloyds Register representatives and were assessed and deemed satisfactory according to Lloyds Register standards. GCDC is therefore certified to meet the shipboard testing requirements for the testing and evaluation of ballast water management systems in accordance with IMO resolution MEPC.174(58) "Guidelines for Approval of Ballast Water Management Systems." Guidelines G8 (IMO 2008, Appendix 1).

The three consecutive shipboard test cycles to test the performance of the Semb-Eco BWMS were undertaken on three voyages of the multi-purpose vessel MV *PAC Suhail* between January and August 2015. The vessel particulars and the dimensions of the test tanks (the control and treated tanks) are shown in Table 1 and Figure 1.

Table 1. Main dimensions of the test vessel and tank details.

Vessel name	PAC Suhail
IMO number	9598945
Flag	Singapore
Class	ABS
Vessel type	Multi-purpose container/bulk carrier
Length overall	180.06 m
Gross Tonnage	21,164 t
Total ballast water capacity	11,119.9 m³
Number of ballast tanks	31
Number of ballast pumps	2
Capacity of ballast pump	500 m³/h
Number of ballast water treatment systems installed	1
Treatment system capacity	500 m³/h
Voyage 1	Control tank: 5 DB WBT STARBOARD
	Treated tank: 5 DB WBT PORT
Voyage 2	Control tank: 6 WING WBT STARBOARD
	Treated tank: 6 WING WBT PORT
Voyage 3	Control tank: 6 WING WBT STARBOARD
	Treated tank: 6 WING WBT PORT

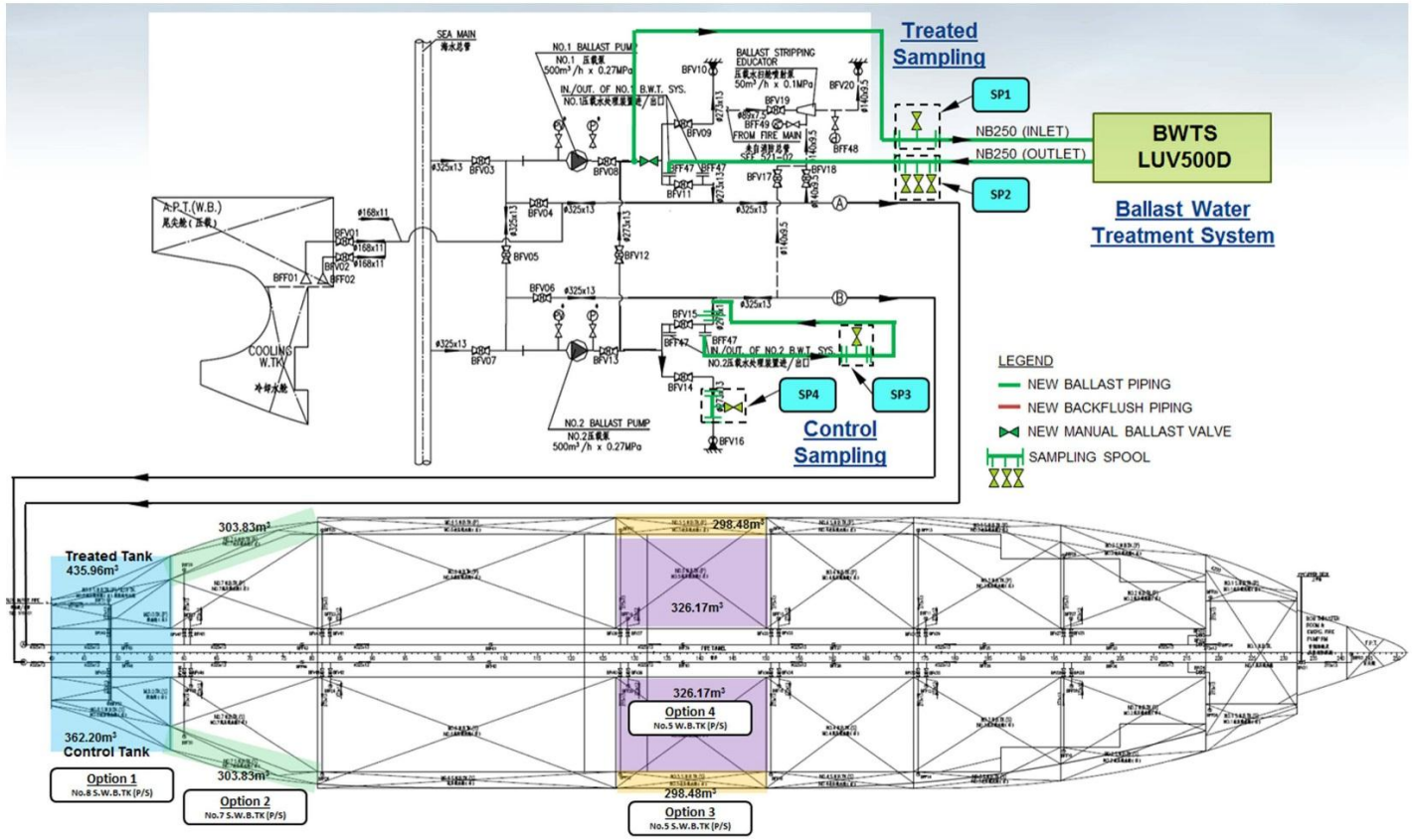

Figure 1. Tank plan of MV *PAC Suhail* also showing the location of the sampling points (SP1, SP2, SP3 & SP4).

The test vessel is in service since May 2012 and calls regularly at several ports in Asia and North America (east coast and Gulf of Mexico).

The BWMS installed onboard MV *PAC Suhail* has a treatment rated capacity of 500 m^3/h. The treatment system was installed and integrated into the ballast system of the vessel in 2014. During the tests the BWMS was operated by representatives of Semb-Eco.

During all G8 test cycles both the control tank and the treated ballast tanks, were filled and emptied as much as possible and this was conducted in parallel for both tanks.

With the exception of the discharge sampling event during the third voyage, all sampling events and the following on board sample processing was audited by different representatives of Lloyd's Register. On the third voyage the ballast water discharge was carried out in the Gulf of Mexico instead of the Port of New Orleans as planned due to the USCG regulations. Due to life boat and cabin limitations the Lloyd's Register surveyor was unable to sail with the vessel. For these reasons the surveyor was unable attend the discharge sampling event in person, but he met the sampling team on board of the test vessel when she was in New Orleans and interviewed both the sampling team and the representatives of Semb-Eco as agreed with both Lloyd's Register and Singapore Administration.

All samples were taken during the ballast water uptake and discharge time in accordance with the GCDC Sampling Protocol (Gollasch et al. 2014) and the additional explanation of the sampling approach (see Appendix 2) which was approved by Lloyd's Register and Singapore Administration.

The ballast water test sampling were carried out as follows:

- Test cycle 1, uptake at the Port of Phuket, Thailand, discharge at the Port of Padang, Indonesia;
- Test cycle 2, uptake at the Port of Morehead City, USA, discharge at the Port of Baltimore, USA; and
- Test cycle 3, uptake at the Port of Corpus Christi, USA, discharge in the Gulf of Mexico before entering the Port of New Orleans, USA.

The holding time of the ballast water in the tank between uptake and discharge was between 68 and 98 hours (Figure 2).

During all test cycles all samples were taken and processed by GCDC sampling team members, i.e. Dr. Stephan Gollasch and Dr. Matej David.

The chain of custody was guaranteed as the samples to be delivered to the land-based laboratories were transported by GCDC staff so that external manipulation of the samples was impossible. In addition the samples were sealed with stickers, which were stamped and signed by the Lloyd's Register representative. An example is given as Figure 3.

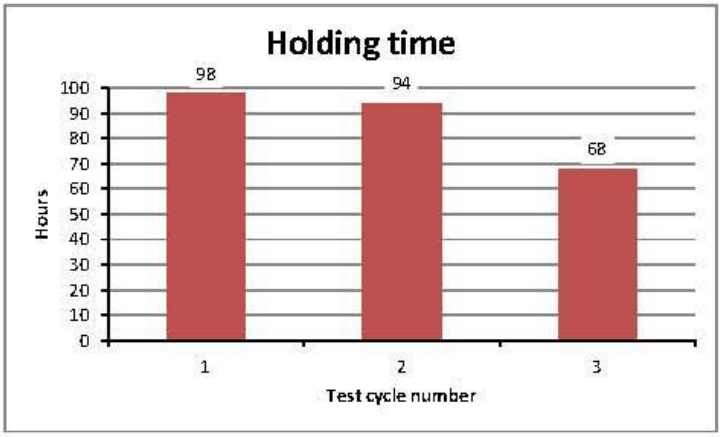

Figure 2. Approximate in-tank holding time of the treated ballast water between uptake and discharge during all test cycles.

Figure 3. Stamped and signed phytoplankton samples as they arrived at the land-based laboratory NIOZ for processing.

2. Sampling scenario

With reference to the GCDC Sampling Protocol for Shipboard Tests of the PAC Suhail/PAC Shaula Ballast Water Management System (Gollasch et al. 2014), multiple HydroBios ballast water sampling kits were used during each test cycle (Figures 4 & 5). For the discharge sampling event the ballast water samples were collected by using three sampling kits in parallel (Figure 6).

Figure 4. Sampling arrangements with Stephan Gollasch taking a phytoplankton sample.

Figure 5. Sampling arrangements with Matej David taking a phytoplankton sample.

Figure 6. Sampling arrangements for replicate sampling.

Sample processing was conducted on board as soon as possible after the sampling events were completed:

- Plankton organisms larger than 50 micron in minimum dimension were analysed directly after sampling;
- The sample processing of indicator microbes *E. coli* and *Enterococci* samples was also conducted directly after sampling and if needed the incubation time was completed on land in a hotel room;
- Cholera bacteria samples were prepared for later analysis by the laboratory IBEN, Bremerhaven, Germany;
- The samples for
    - total suspended solids (TSS);
    - particulate organic carbon (POC); and
    - plankton less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension;

  were prepared directly after sampling and the samples were stored in a fridge on board/hotel rooms or with cooling elements in Styrofoam boxes during transport. The samples were analysed by the laboratory NIOZ, Texel, the Netherlands as soon as possible after the voyage. Sample transport was arranged with the GoConsult courier.

Procedures for sample processing as outlined in the test protocol (Gollasch et al. 2014) were followed. The protocol was prepared in line with the most up-to-date version of the IMO Guideline G8 *Guidelines for the Approval of Ballast Water Management Systems* (IMO 2008). The following samples were taken and processed in addition to the requirements of IMO G8 Guidelines:

- Analysis of environmental and biological parameters of the uptake treated water;
- Analysis of environmental parameters of the discharged treated water;
- Analysis of environmental parameters of the discharged control water; and
- Analysis of bacteriae of the discharged control water.

These additional samples were taken and processed and the results are included in Tables 2, 3 and 4 below.

3. Results

Results regarding environmental parameters and the biological analysis of the samples are shown in Tables 2, 3 and 4 below. As stated above additional environmental parameters and biological analysis than required by the IMO G8 Guidelines were conducted.

Environmental parameters

The results in Tables 2, 3 and 4 show values of environmental parameters as measured in the ballast water uptake regions.

Biological results

The minimum intake concentrations of organisms for valid tests according to the IMO G8 Guidelines section 2.2.2.5 (challenge water) were met in all test cycles.

The blank test of the distilled water used to water the bacteria media were all negative so that no bacteria contamination from the media or distilled water occurred.

The results show that the Semb-Eco BWMS complied with the ballast water performance standards as stated in Regulation D-2 of the IMO Ballast Water Management Convention (IMO 2004). This is valid for the discharge of the treated ballast water of all test cycles and for all organism groups addressed in Regulation D-2.

IMO Test Cycle 1

Date and time for ballast water **uptake**: 20 January 2015, 09:30hr to 09:57hr

Position of ship during start of ballast water uptake:
- Port of Phuket, Thailand
- Water depth approximately 14 m.

Date and time for ballast water **discharge**: 24 January 2015, 12:05hr to 12.42hr

Holding time of ballast water between uptake and discharge: approximately 98 hrs.

Weather conditions during the test: good, calm wind.

Table 2. Results of Test Cycle 1.
(nd = not detectable).

Parameter	Unit	Uptake water			Discharge water						
		control	before treat-ment	IMO	Control	IMO	Treated			aver.	IMO
							# 1	# 2	# 3	#1-#3	
Temperature	°C	28.6	28.4	-	29.4	-	29.4	29.4	29.4	-	-
Salinity	PSU	31.8	31.6	-	31.6	-	31.4	31.4	31.2	-	-
POC *	mg/l	13.6	8.8	-	14.2	-	8.2	7.6	8.2	-	-
TSS *	mg/l	57.8	35.6	-	31.6	-	28.4	30.8	31.4	-	-
Sample vol. >50 µm	Litres	1134	1189	>1000	1735	>1000	1543	1917	1853	-	>1000
Sample vol. 50-10 µm	Litres	6	6	>1	6	>1	6	7	6	-	>1
Sample vol. bacteria	Litres	1	1	>0,5	1	-	1	1	1	-	>0,5
Organisms >50µm	org./1m³	4392	3440	>90	1389	>10	nd	nd	nd	nd	<10
Organisms 10-50µm*	org./1ml	286	319	>90	84	>10	1	1	nd	0.7	<10
Escherichia coli	cfu/100ml	4	8	-	nd	-	nd	nd	nd	nd	<250
Intestinal *Enterococci*	cfu/100ml	100	18	-	24	-	1	5	1	2.3	<100
*Vibrio cholerae***	cfu/100ml	nd	nd	-	nd	-	nd	nd	nd	nd	<1

* Samples analysed at NIOZ, Texel. ** Samples analysed at IBEN, Bremerhaven.

IMO Test Cycle 2

Date and time for ballast water **uptake**: 14 March 2015, 10:34hr to 11:05hr

Position of ship during start of ballast water uptake:

- Port of Morehead, USA
- Water depth approximately 14 m.

Date and time for ballast water **discharge**: 18 March 2015, 08:42hr to 09:19hr

Holding time of ballast water between uptake and discharge: approximately 94 hrs.

Weather conditions during the test: good, no wind.

Table 3. Results of Test Cycle 2.
(nd = not detectable).

Parameter	Unit	Uptake water			Discharge water						
		control	before treat-ment	IMO	Control	IMO	Treated			aver.	IMO
							# 1	# 2	# 3	#1-#3	
Temperature	°C	11.4	11.3	-	7.1	-	7.1	7.1	7.1	-	-
Salinity	PSU	31.9	31.9	-	34.0	-	31.9	31.9	31.9	-	-
POC *	mg/l	12.0	12.6	-	10.4	-	11.4	10.2	10.2	-	-
TSS *	mg/l	24.4	24.2	-	23.0	-	20.0	18.4	15.8	-	-
Sample vol. >50 µm	Litres	1219	1152	>1000	1426	>1000	1499	1529	1541	-	>1000
Sample vol. 50-10 µm	Litres	6	6	>1	6	>1	6	6	6	-	>1
Sample vol. bacteria	Litres	1	1	>0,5	1	-	1	1	1	-	>0,5
Organisms >50µm	org./1m³	2863	2413	>90	252	>10	nd	nd	nd	nd	<10
Organisms 10-50µm*	org./1ml	623	1002	>90	70	>10	1.3	1.0	0.7	1.0	<10
Escherichia coli	cfu/100ml	6	8	-	<5	-	nd	nd	nd	nd	<250
Intestinal *Enterococci*	cfu/100ml	<5	<5	-	<5	-	nd	nd	nd	nd	<100
*Vibrio cholerae***	cfu/100ml	nd	nd	-	nd	-	nd	nd	nd	nd	<1

* Samples analysed at NIOZ, Texel. ** Samples analysed at IBEN, Bremerhaven.

IMO Test Cycle 3

Date and time for ballast water **uptake**: 01 August 2015, 13:54hr to 14:51hr

Position of ship during start of ballast water uptake:

- Port of Corpus Christi, USA
- Water depth approximately 12 m.

Date and time for ballast water **discharge**: 04 August 2015, 10:57hr to 11:57hr

Holding time of ballast water between uptake and discharge: approximately 68 hrs.

Weather conditions during the test: good, calm wind.

Table 4. Results of Test Cycle 3.
(nd = not detectable).

Parameter	Unit	Uptake water			Discharge water						
		control	before treat-ment	IMO	Control	IMO	Treated			aver.	IMO
							# 1	# 2	# 3	#1-#3	
Temperature	°C	29.2	29.2	-	30.6	-	30.3	30.3	30.3	-	-
Salinity	PSU	31.2	31.3	-	31.7	-	32.1	32.1	32.1	-	-
POC *	mg/l	26.5	26.0	-	17.4	-	15.8	15.5	15.5	-	-
TSS *	mg/l	53.0	50.0	-	29.7	-	24.8	25.5	27.5	-	-
UV *** Intensity	W/m²	225	-	-	-	-	328	323	323	325	-
UV *** transmittance	%	76.2	-	-	-	-	93.5	94.9	94.0	94.1	-
Sample vol. >50 µm	Litres	1292	1480	>1000	1305	>1000	1626	1624	1628	-	>1000
Sample vol. 50-10 µm	Litres	6	6	>1	6	>1	6	6	6	-	>1
Sample vol. bacteria	Litres	1	1	>0,5	1	-	1	1	1	-	>0,5
Organisms >50µm	org./1m³	7314	4534	>90	3448	>10	nd	nd	nd	nd	<10
Organisms 10-50µm*	org./1ml	104	100	>90	38	>10	nd	nd	1	0.3	<10
Escherichia coli	cfu/100ml	90	70	-	<5	-	nd	<5	nd	1.7	<250
Intestinal *Enterococci*	cfu/100ml	<10	<5	-	nd	-	nd	nd	nd	nd	<100
*Vibrio cholerae***	cfu/100ml	nd	nd	-	nd	-	nd	nd	nd	nd	<1

* Samples analysed at NIOZ, Texel. ** Samples analysed at IBEN, Bremerhaven. *** Data provided by Semb-Eco.

4. Discussion of the results

The Semb-Eco BWMS was intensively tested during the three test voyages in which three test cycles were undertaken in total (January to August 2015). The tests were conducted in different environmental water conditions and different seasons resulting in varying organism concentrations in the uptake water.

During all on board tests, sample taking, sample processing and sample forwarding was always conducted as outlined in the agreed sampling protocol (Gollasch et al. 2014).

All required samples were taken to document the abiotic and biotic water conditions during the tests. Apart from IMO G8 Guidelines requirements, additional samples were taken and all samples were analysed for additional parameters.

The minimum water volumes of all sample types, as stated in the IMO G8 Guidelines, were met during all tests.

For the control experiment the intake and discharge water met the IMO G8 Guidelines organisms requirements.

The minimum organism intake concentrations to challenge the treatment system exceeded the required numbers as stated in the IMO G8 Guidelines for all test cycles.

The treated water at discharge of all test cycles met the Ballast Water Performance Standard as stated in Regulation D-2 of the IMO Ballast Water Management Convention (IMO 2004).